Electromagnetic Transition Rate Studies with the TIGRESS Integrated Plunger

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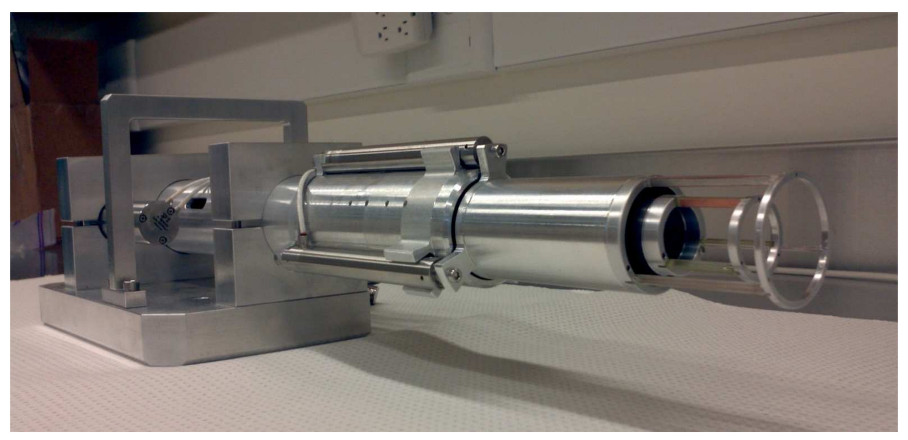
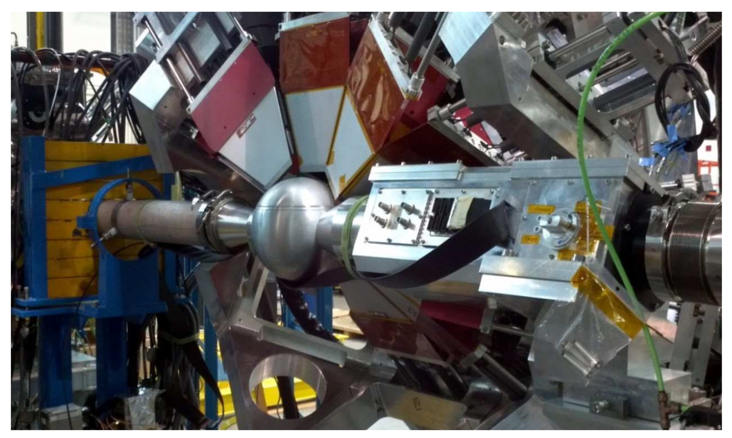
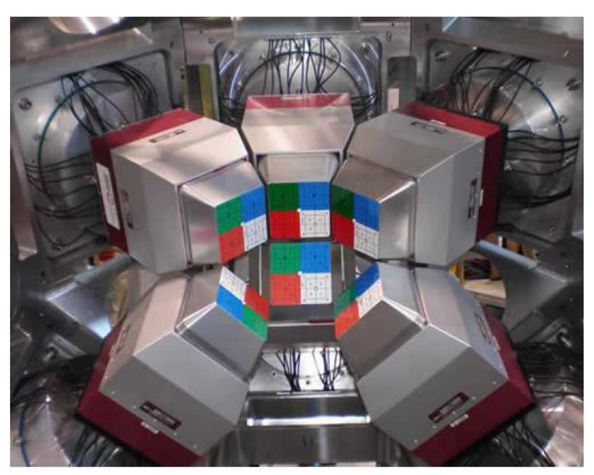
Introduction

- Precise transition rate measurements are fundamental probes of nuclear structure and permit stringent tests for theoretical models important to our understanding of the nucleus.
- The TIGRESS Integrated Plunger (TIP) delivers a new experimental program for transition rate studies via Doppler-shift lifetime and sub-barrier Coulomb excitation measurements using accelerated radioactive beams from the ISAC-II facility at TRIUMF.
- Experimental and developmental work on TIP and its extensive suite of ancillary charged-particle detector systems has been focused on probing nuclear structure along the *N=Z* line.
  - Impact of increasing neutron deficiency on shape evolution of medium mass nuclei.
  - Quality of shell model descriptions of the properties of low-lying levels in light nuclei.

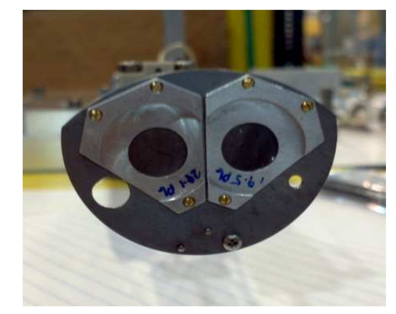
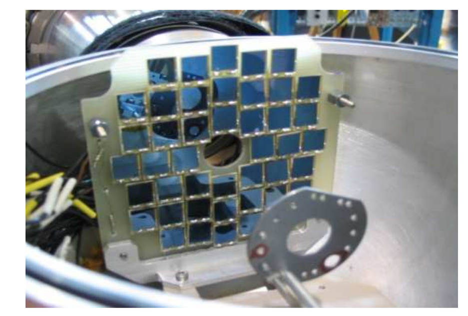
The TIGRESS Integrated Plunger

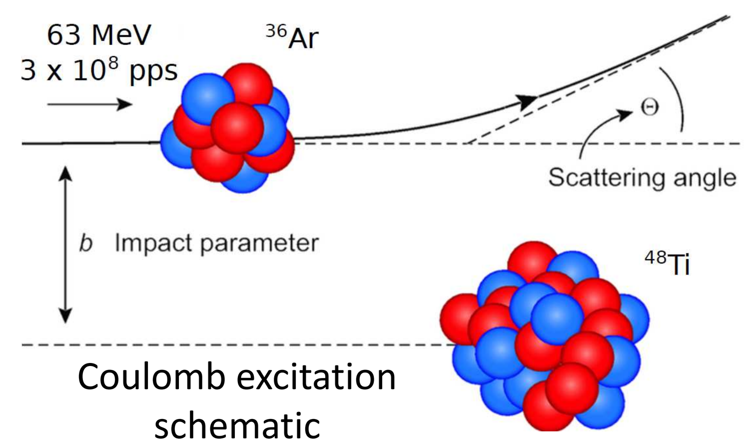




- Plunger gamma-ray spectra are collected with TIGRESS for recoil distance method lifetime measurements.
- TIGRESS is an array of HPGe segmented clover detectors with BGO suppressors and fast digital electronics.
- Future TIP lifetime studies of weak and exotic reaction channels will benefit from new spectroscopy tools: EMMA (ElectroMagnetic Mass Analyser) and DESCANT (Deuterated Scintillator Array for Neutron Tagging).

Transition Rate Discrepancies in ^{36}Ar

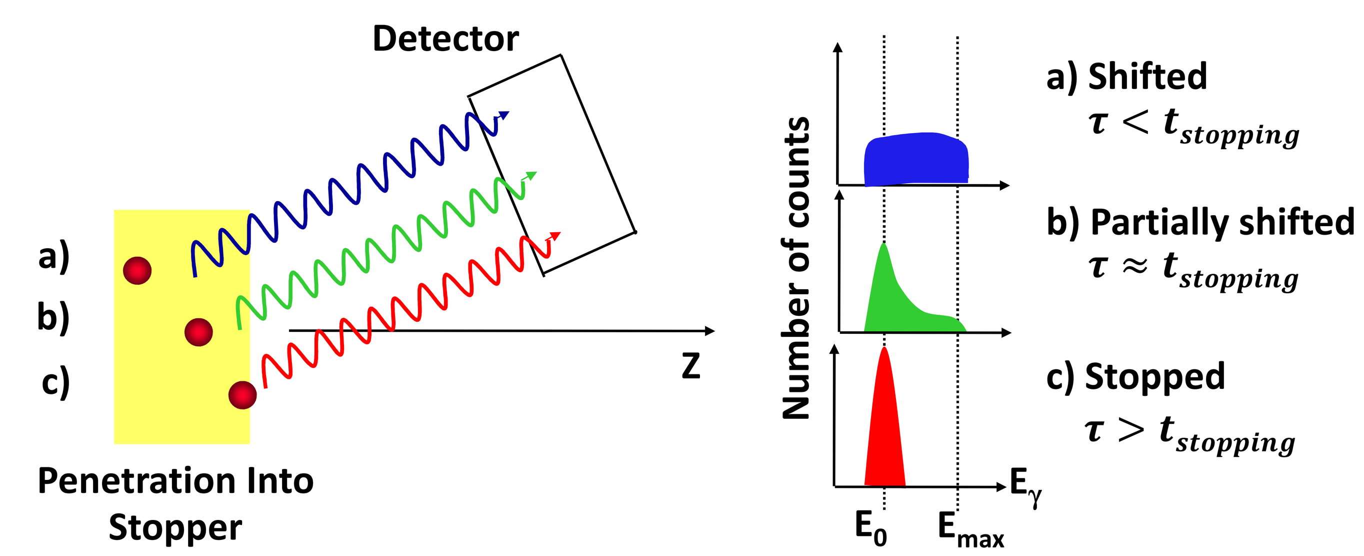
Doppler-shift attenuation method (DSAM) lifetime and sub-barrier Coulomb excitation data have been collected with the TIP target wheel and ancillary silicon detector systems to help resolve recent transition rate discrepancies in ^{36}Ar.



Coulomb excitation schematic

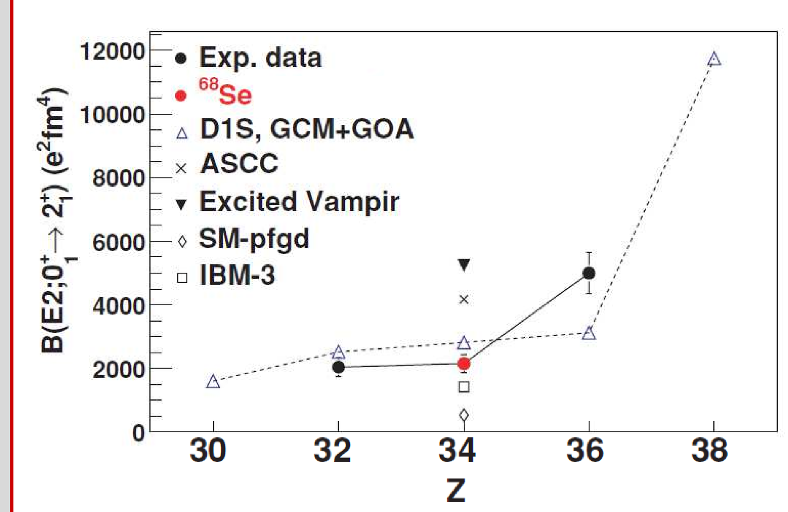
Source	$B(E2;0^+_1 \to 2^+_1)$ [e^{2}fm^4]	τ [ps]
DSAM [1]	211(6)	0.65(2)
Shell Model [1]	322(*)	0.43(*)
Int. En. Coulex [2]	286(23)	0.48(4)
Int. En. Coulex [3]	310(31)	0.44(4)

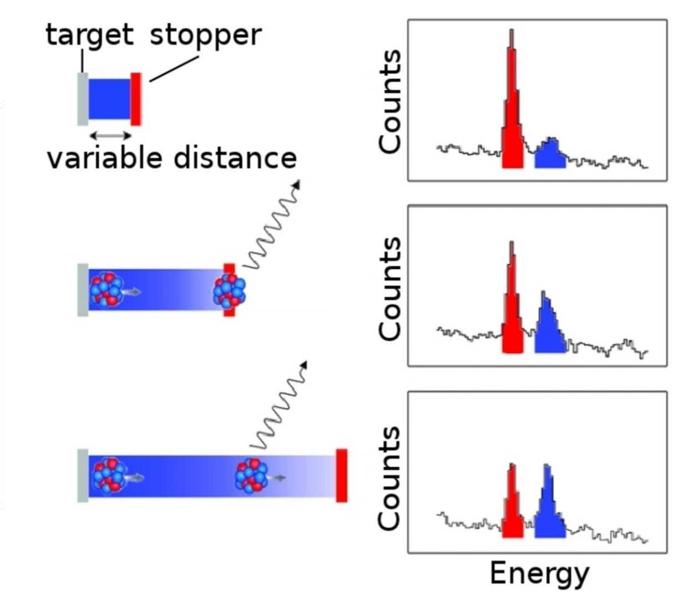


DSAM schematic for stopper of thickness $d = v \cdot t_{stopping}$

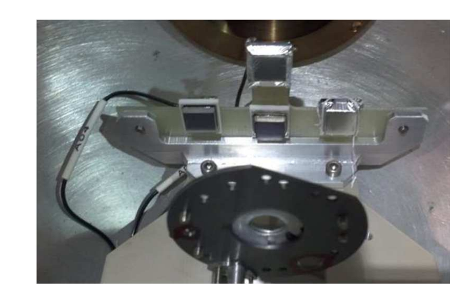
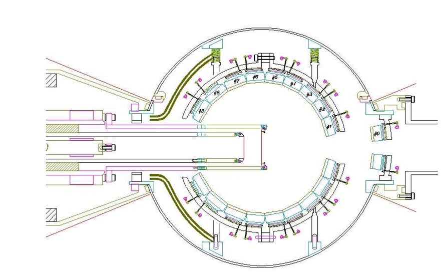
Nuclear Shape Evolution and ^{68}Se

- Along the *N=Z* line, protons and neutrons occupy the same shell model orbitals. The large wave function overlap leads to an amplification of their interactions, which drives a steady deformation of nuclear shapes between ^{56}Ni and ^{100}Sn.
- *B(E2)* transition strength model calculations vary by an order of magnitude. Data (shown below from Ref. [4]) from intermediate energy Coulomb excitation indicate the shape evolution from ^{64}Ge to ^{68}Se is suppressed.
- TIP will provide a direct, model-independent, and complimentary transition rate measurement following fusion-evaporation reactions via Doppler-shift lifetime measurements.



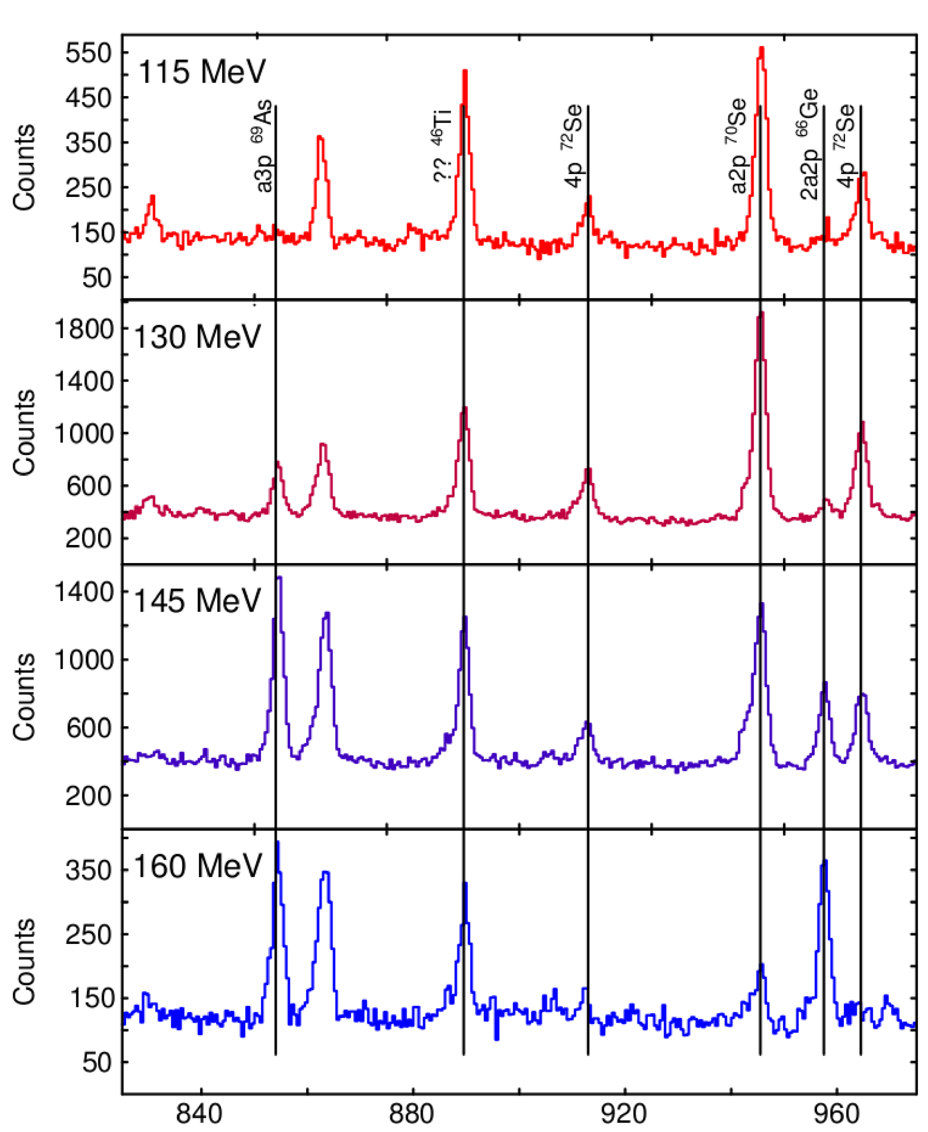


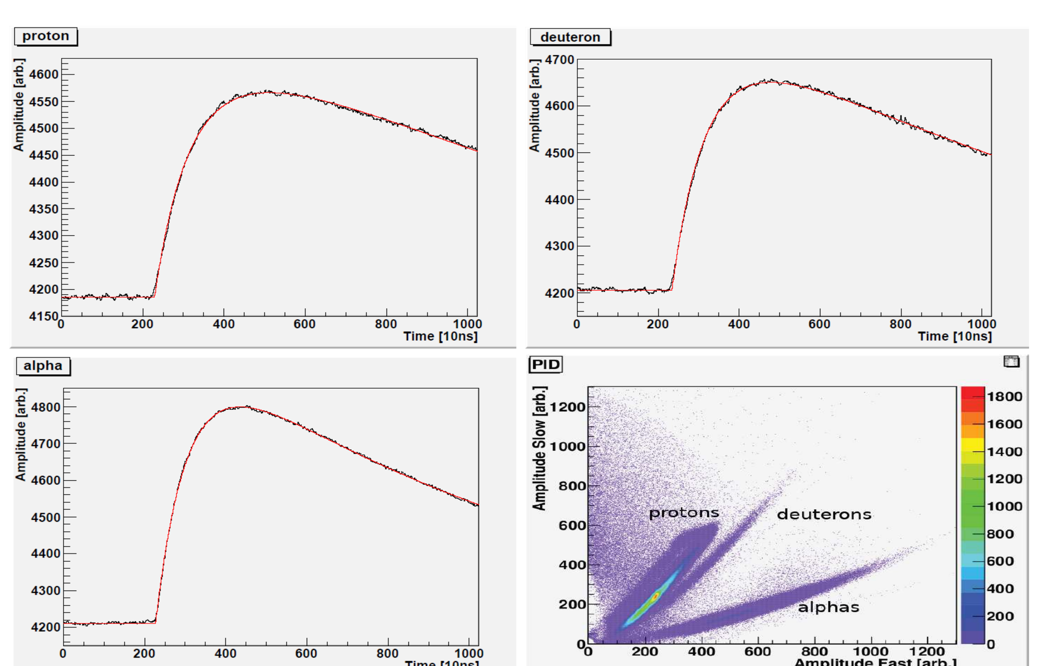
- The ^{40}Ca(^{36}Ar, 2α)^{68}Se reaction channel will be selected with evaporated light-particle detection using the TIP CsI(Tl) ball, which will offer nearly 3π coverage.
- Integration of the CsI array into the TIGRESS DAQ will permit pulse-shape analysis of the collected waveforms to enable reaction channel selectivity.

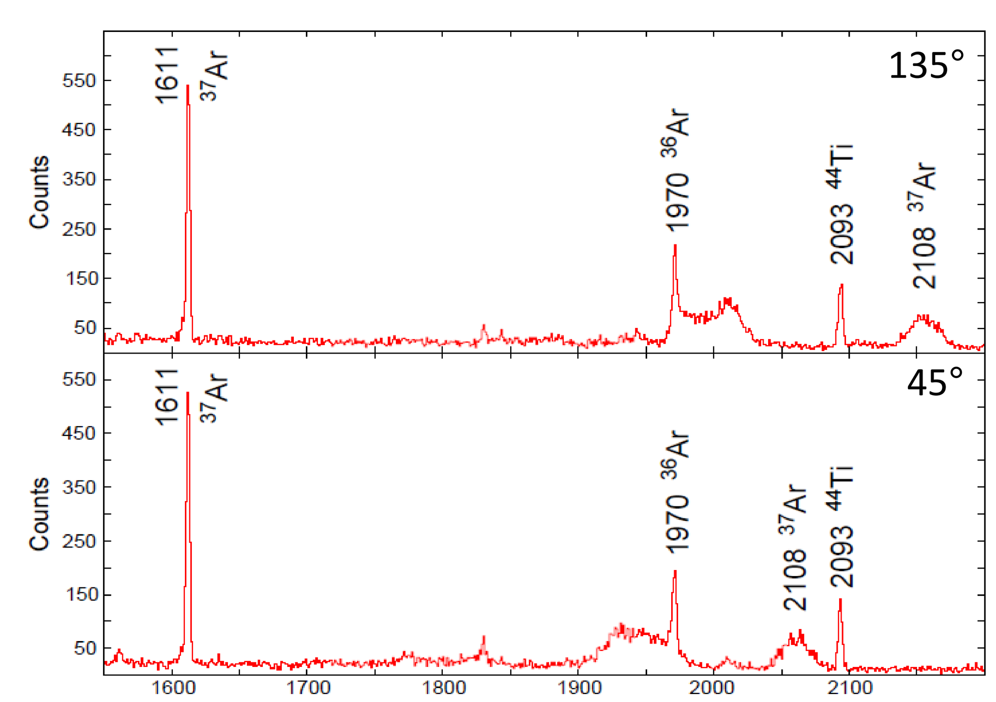




Various stages of development of the TIP CsI ball.

Present Analysis and Results from TIP







- [Left] ^{36}Ar beam energies of 115, 130, 145, and 160 MeV were delivered onto a ^{40}Ca target and the fusion-evaporation reaction channels were identified by gamma-ray energies. A qualitative analysis of the excitation function was performed and compared to PACE4 calculations to determine the optimal ^{68}Se production beam energy.
- [Middle] Prototype CsI(Tl) crystals coupled to silicon PIN diodes were used for evaporated charged-particle identification via pulse-shape analysis of the excitation function data.
- [Right] Gamma-ray decay energy spectra at forward (45°) and backward (135°) TIGRESS angles following the Coulomb excitation of ^{36}Ar on a gold-backed carbon target. Gamma-rays were collected in coincidence with recoiling carbon nuclei.

Summary

- Electromagnetic transition rate measurements with accelerated radioactive beams play an important role in our understanding of nuclear structure.
- The TIGRESS Integrated Plunger and associated ancillary detector systems offer a high degree of flexibility for precise Doppler-shift lifetime and sub-barrier Coulomb excitation studies along the *N=Z* line.
- Experimental and analytical efforts towards resolving discrepancies in the self-conjugate ^{36}Ar system are underway.
- Work continues to fully develop TIP and the CsI array for transition rate studies of exotic nuclei far from stability.

Acknowledgements

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